Petrology Experiment Module

UCSI
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Objective:

- The participant can recognize the mineral, texture, and structure of the rocks which also included the types of the rock macroscopic.
- The participant can describe each type of rock correctly and efficiently.

Material:

Weeks	Date	Material
1		Introduction and description of mineral (Bowen's series mineral)
2		Igneous Rock identification and description
3		Sedimentary Rock identification and description
4		Metamorphic Rock identification and description
5		Rock Porosity determination
6		Major Element Analysis of Rock and Sediments by Atomic Absorption Spectroscopy

Description Log

Name :

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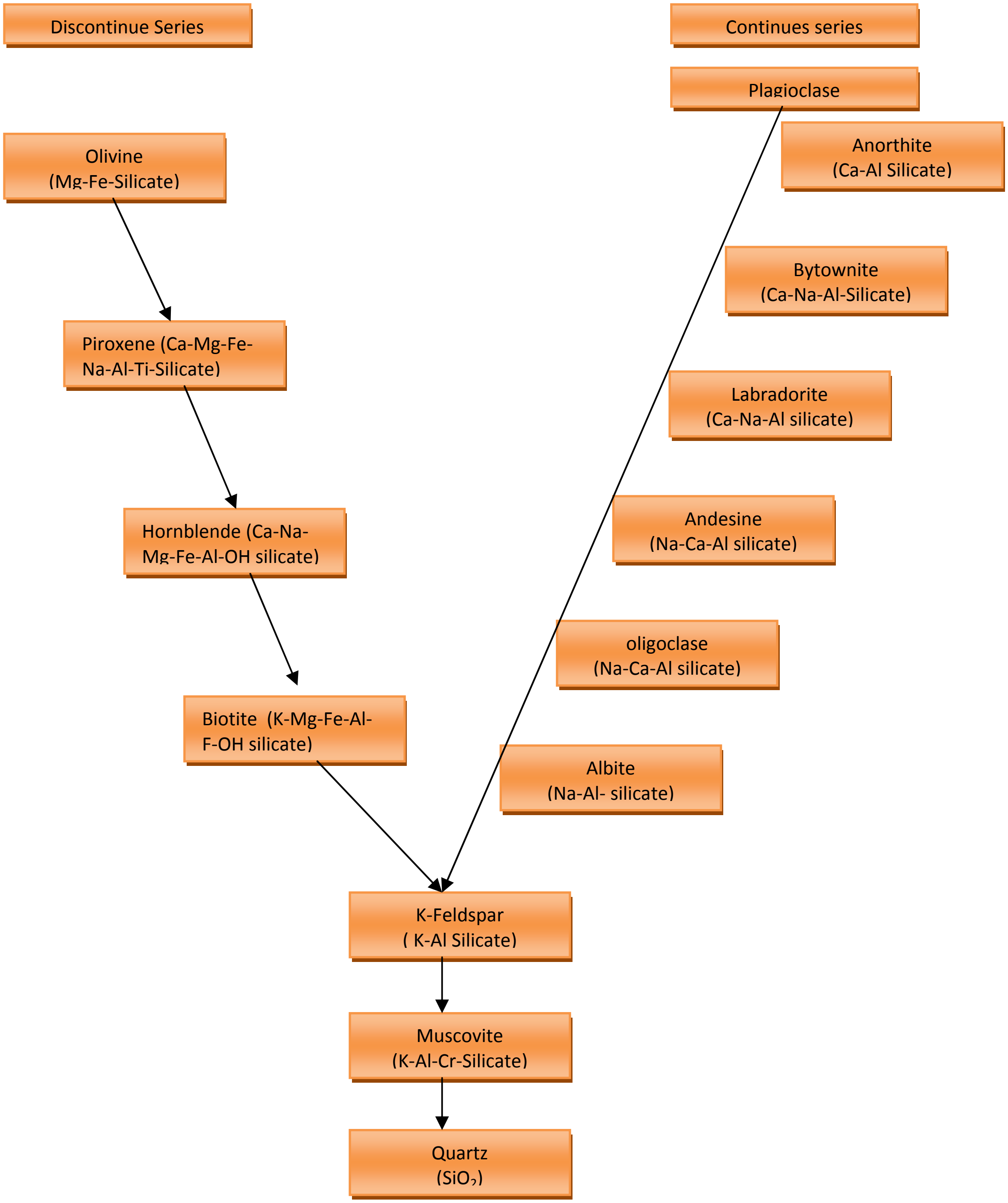
Sketch

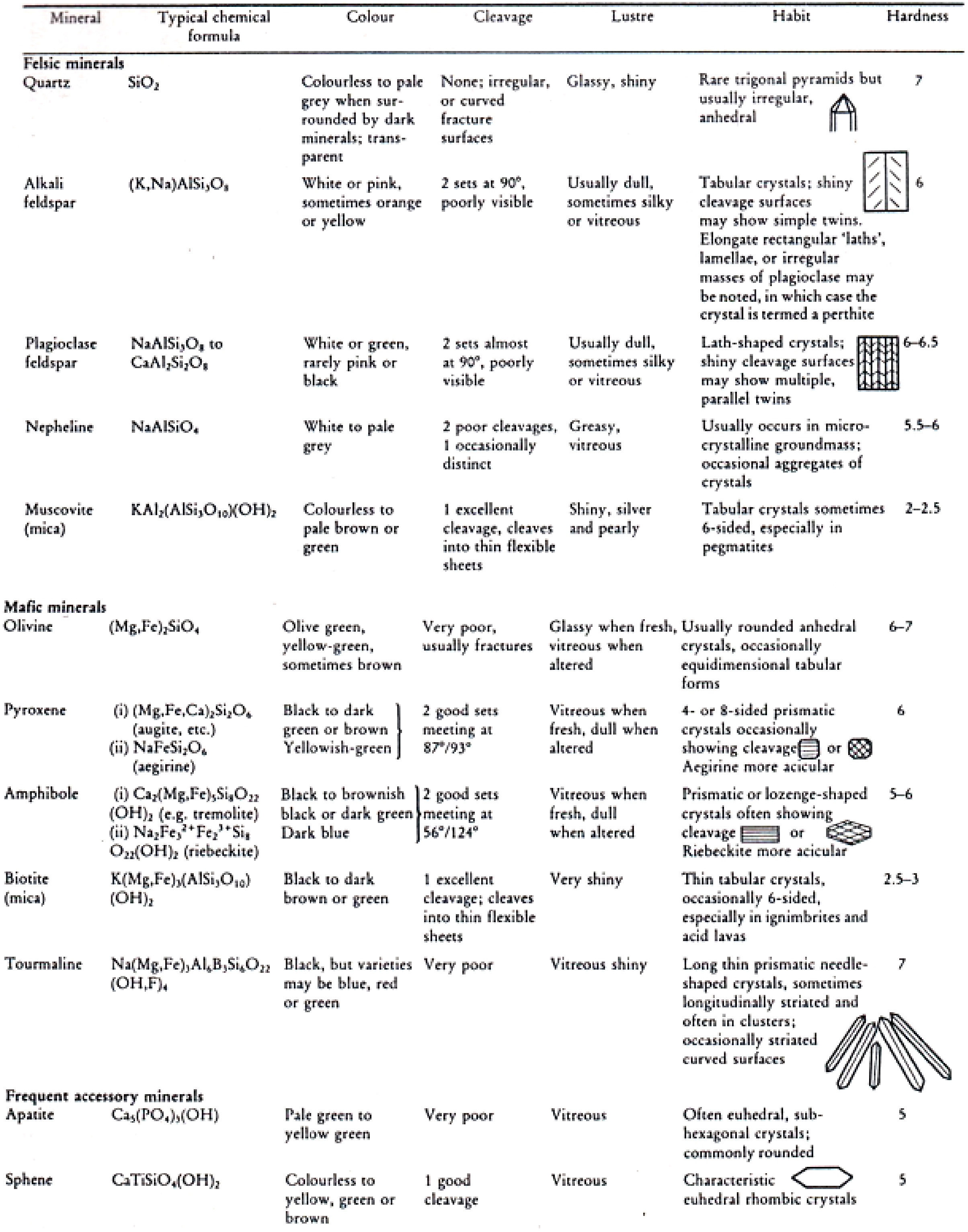
I. Identification of Bowen's Series

Bowen has formulated the crystallization of igneous major minerals which known as Bowen's series reaction:


Discontinue Series
Continues series
Plagioclase
Olivine (Mg-Fe-Silicate)
Anorthite (Ca-Al Silicate)
Bytownite (Ca-Na-Al-Silicate)
Piroxene (Ca-Mg-Fe-Na-Al-Ti-Silicate)
Labradorite (Ca-Na-Al silicate)
Andesine (Na-Ca-Al silicate)
Hornblende (Ca-Na-Mg-Fe-Al-OH silicate)
oligoclase (Na-Ca-Al silicate)
Biotite (K-Mg-Fe-Al-F-OH silicate)
Albite (Na-Al- silicate)
K-Feldspar (K-Al Silicate)
Muscovite (K-Al-Cr-Silicate)
Quartz (SiO_2)

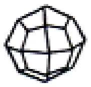
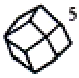
The characteristics of Bowen's mineral and other igneous mineral are shown on Table 1 & 2.

Table 1: Major Igneous Rock Mineral Characteristic



Mineral	Typical chemical formula	Colour	Cleavage	Lustre	Habit	Hardness
Felsic minerals						
Quartz	SiO_2	Colourless to pale grey when surrounded by dark minerals; transparent	None; irregular, or curved fracture surfaces	Glassy, shiny	Rare trigonal pyramids but usually irregular, anhedral	7
Alkali feldspar	$(K,Na)AlSi_3O_8$	White or pink, sometimes orange or yellow	2 sets at 90°, poorly visible	Usually dull, sometimes silky or vitreous	Tabular crystals; shiny cleavage surfaces may show simple twins. Elongate rectangular 'laths', lamellae, or irregular masses of plagioclase may be noted, in which case the crystal is termed a perthite	6
Plagioclase feldspar	$NaAlSi_3O_8$ to $CaAl_2Si_2O_8$	White or green, rarely pink or black	2 sets almost at 90°, poorly visible	Usually dull, sometimes silky or vitreous	Lath-shaped crystals; shiny cleavage surfaces may show multiple, parallel twins	6–6.5
Nepheline	$NaAlSiO_4$	White to pale grey	2 poor cleavages, 1 occasionally distinct	Greasy, vitreous	Usually occurs in microcrystalline groundmass; occasional aggregates of crystals	5.5–6
Muscovite (mica)	$KAl_2(AlSi_3O_{10})(OH)_2$	Colourless to pale brown or green	1 excellent cleavage, cleaves into thin flexible sheets	Shiny, silver and pearly	Tabular crystals sometimes 6-sided, especially in pegmatites	2–2.5
Mafic minerals						
Olivine	$(Mg,Fe)_2SiO_4$	Olive green, yellow-green, sometimes brown	Very poor, usually fractures	Glassy when fresh, vitreous when altered	Usually rounded anhedral crystals, occasionally equidimensional tabular forms	6–7
Pyroxene	(i) $(Mg,Fe,Ca)_2Si_2O_6$ (augite, etc.) (ii) $NaFeSi_2O_6$ (aegirine)	Black to dark green or brown Yellowish-green	2 good sets meeting at 87°/93°	Vitreous when fresh, dull when altered	4- or 8-sided prismatic crystals occasionally showing cleavage ▤ or ▩ Aegirine more acicular	6
Amphibole	(i) $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$ (e.g. tremolite) (ii) $Na_2Fe_3^{2+}Fe_2^{3+}Si_8O_{22}(OH)_2$ (riebeckite)	Black to brownish black or dark green Dark blue	2 good sets meeting at 56°/124°	Vitreous when fresh, dull when altered	Prismatic or lozenge-shaped crystals often showing cleavage ▤ or ▩ Riebeckite more acicular	5–6
Biotite (mica)	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	Black to dark brown or green	1 excellent cleavage; cleaves into thin flexible sheets	Very shiny	Thin tabular crystals, occasionally 6-sided, especially in ignimbrites and acid lavas	2.5–3
Tourmaline	$Na(Mg,Fe)_3Al_6B_3Si_6O_{22}(OH,F)_4$	Black, but varieties may be blue, red or green	Very poor	Vitreous shiny	Long thin prismatic needle-shaped crystals, sometimes longitudinally striated and often in clusters; occasionally striated curved surfaces	7
Frequent accessory minerals						
Apatite	$Ca_5(PO_4)_3(OH)$	Pale green to yellow green	Very poor	Vitreous	Often euhedral, sub-hexagonal crystals; commonly rounded	5
Sphene	$CaTiSiO_4(OH)_2$	Colourless to yellow, green or brown	1 good cleavage	Vitreous	Characteristic euhedral rhombic crystals	5

Table 2: Common minerals characteristic on igneous rock

Mineral	Typical chemical formula	Colour	Cleavage	Lustre	Habit	Hardness
Frequent Accessory Minerals (contd.)						
Garnet	$(Mg,Fe)_3Al_2Si_3O_{12}$ (also Ca, Mn)	Red, brown or yellow	Poor	Usually resinous or dull, good crystals may be glassy	Equidimensional crystals often showing faces typical of cubic system, e.g. dodecahedra and trapezohedra. Common in meta-granites. 	6–7
Leucite	$KAlSi_2O_6$	White or grey	None	Vitreous or resinous	Often euhedral trapezohedral crystals in alkaline lavas 	5.5–6
Hematite	Fe_2O_3	Red to red-brown, sometimes black	None	Dull	Usually fine and powdery, occasionally scaly or fibrous crystals	5.5–6
Magnetite, (a spinel mineral)	Fe_3O_4	Black, brownish-black	Poor	Metallic, dull	Small equidimensional granular crystals, occasional cubes or octahedra	5.5
(Other spinels are $M^{2+}M_2^{3+}O_4$ where M^{2+} is Fe, Mg, Mn, Zn, etc. and M^{3+} is Al, Fe, Cr, etc. e.g. dark brown to black *chromite*, $FeCr_2O_4$, which occurs in some peridotites)						
Ilmenite	$FeTiO_3$	Black, brownish black or grey	None	Metallic or dull	Thin plates or scales usually elongate crystals, sometimes rod-like	5.6
Monazite	$(Ce,La,Th)PO_4$	Pale yellow to dark brown	Moderate single cleavage	Resinous	Thick tabular crystals in granites and gneisses	5–5.5
Secondary minerals (See also Table 8.2)						
Calcite	$CaCO_3$	White, translucent	3 sets rhombohedral	Vitreous, rarely glassy	Usually granular or fibrous in igneous rocks, common in veins, cavities, etc. NB Reacts with dilute acid	3
Zeolite group	e.g. $(Na_2Ca)(Al_2Si_3O_{10}).nH_2O$ (n varies from 2 to 8)	White, pale yellow or pale green, rarely pink, red or blue	Variable according to mineral type	Usually vitreous or silky	Massive or granular crystals lining cavities, particularly, amygdales; radiating fibrous clusters or needles	5–6
Clay group	e.g. $Al_4Si_4O_{10}(OH)_8$ (kaolinite)	White to pale browns and greens	Good, but not visible in hand specimens	Dull	Fine powdery aggregates replacing mainly feldspar in igneous rocks	1
Epidote	$CaFe^{3+}Al_2Si_3O_{12}(OH)$	Pale yellows and apple green, rarely brown or red	1 good cleavage	Vitreous	Variable, often elongated crystals, needles and radiating groups, coarsely crystalline varieties in hydrothermal veins and vesicles	6–7
Chlorite	$(Mg,Al,Fe)_6(Si,Al)_8O_{20}(OH)_4$	Mid-green to dark greenish-yellow	1 good cleavage gives thin sheets	Dull to pearly and 'micaceous'	Usually aggregates of fine crystals, sometimes thin tabular flakes replacing mafic minerals in igneous rocks	2–3
Pyrite	FeS_2	Brassy yellow, occasionally brown or black	Poor	Metallic; iridescent tarnish	Often good cubic crystal faces, occasionally striated. Granular aggregates, particularly along veins in igneous rocks	6–6.5

II. Igneous Rock

Igneous rock is forming from the cooling and crystallization of the magma on the way the magma go to the surface. Magma is a hot and incandescent liquid silicate, which is consist of O, Si, Al, Fe, Mg, Ca, Na, K and so on. The crystallization of magma forming several type of mineral, which is, followed the rule of magma crystallization. Based on the existing mineral, igneous rock can be divided into four major groups of rocks (Table 3).

Table 3: Group of igneous rock based on the presence of group of major minerals

Group of Mineral	Group of Igneous Rock
Olivine Piroxene Plagioclase Olivine, piroxene	Ultramafic and ultramafitit
Olivine, pyroxene, plagioclase Olivine, plagioclase Pyroxene, plagioclase	Gabroid and Basaltoid
Piroxene, hornblende, plagioclase Hornblende, plagioclase Hornblende, biotite, plagioclase, <<<quartz	Dioritoid and Andesitoid
Hornblende, biotite, muscovite, quartz Biotite, muscovite, k-feldspar, quartz Biotite, muscovite, k-feldspar	Granitoid and Dacitoid

II.1 Igneous Rock Texture

Texture is the appearances of rock, which reflected the forming history. Several factors that influence igneous rock texture forming are degree of crystallization, size of grain (granulite), and fabric.

1. Degree of Crystallization
    - Holocrystalline: the whole rock is made by crystal.
    - Hipocrystalline: some of the rock is crystal and some other is glass.
    - Holohyaline: the whole rock is made by glass.
2. Granulite/grain size

    Divided into two big groups:

    - Phaneritic: those crystal can be seen by naked eye. Normally this type, the size of grain can be determined as follow:
        - Fine : < 1mm
        - Medium : 1 mm – 5mm
        - Coarse : 5 mm – 3 cm
        - Very coarse : > 3cm
    - Aphanitic: the crystals very fine or amorphous (glass), which only can be seen by using microscope. If the igneous rock has porphyritic texture, than the phenocrysts and the matrix can be separate.
3. Fabric

    This type of texture is based on the uniformity of grain or crystal, which can be divided into two classes.

    - Equigranular : has relatively same grain size.
    - Inequigranular : the size of the grain not same, which can divided into two:
        - Porphyritic: the crystals, which are bigger, are embedded on groundmass (matrix) which is much smaller than the crystal.
        - Vetrophyric: the crystals, which are bigger, are embedded on an amorphous groundmass.

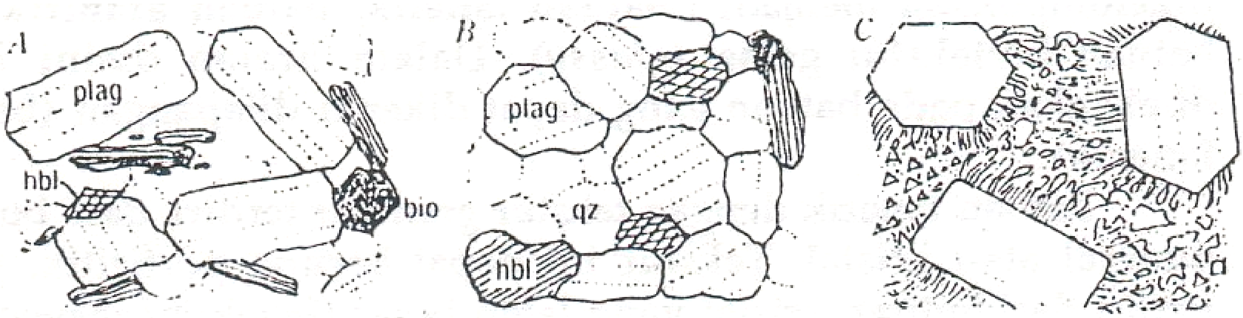


Figure 1. Texture on phaneritic rock, a. hipidiomorphic granular, b.alotriomorphic granular, c.porphyritic.

II.2 Igneous Rock Structure

Structure in this context refers to the primary structure, which is form together with the forming of the igneous rock. The structure of igneous rock only can be found in the field (huge dimension), but some time it also can be seen on hand specimen.

Structure that related with the magma flow:

- Schilieren: the prismatic, flat (long shape) mineral or xenolith is forming a parallel structure because of the flow of magma.
- Segregation: structure that showing groups of mineral (usually the mafic mineral) because of the composition differences between the mineral and the source rock.
- Pillow lava: structure that caused by the lava flow contact with water environment, the shape almost like a pillow, where the up part convex and the lower part concave.

Structure that related with magma cooling:

- Vesicular: in the surface of the igneous rock (lava) has many holes because of gas release.
- Amygdaloidal: holes because of gas release on the lava, are being fill by the secondary mineral, such as zeolite, calcite, quartz.
- Columnar joint: joint that has a shape like a pillar, which the vertical axes is perpendicular with the flow of magma.
- Sheeting joint: joint that has a shape like sheet, usually on the side or top of big intrusion, and was form because of losing pressure.

II.3 Classification of Igneous Rock Megascopic

Based on IUGS classification (1973) of Igneous rock by megascopic can be divided into two big groups:

1. Phaneritic Group

   Rock with this texture can be descript megascopicly (naked eye), have a medium-coarse grain (> 1mm). This group can be divided into few type of rock as shown on Figure 4. The basic idea of the classification was based on the quartz mineral or feldsphatoid mineral, alkali feldspar and plagioclase mineral.

2. Aphanitic Group

   Igneous rock with aphanitic texture, the mineral cannot be distinguished by using naked eye or loupe. Generally has a fine size (<1 mm), therefore this type of rock cannot be determine by using the mineralogy percentage. One of the best way to classified this type of rock is through is color, because the rock color indicating the its mineral. In this case, felsic mineral identically with bright color and mafic mineral identically with dark color. For igneous rock that has porphyritic or vitrophyric can be determine by calculating the percentage of its phenocrysts (Figure 5).

Certain criteria that need to take note when rock description:

1. Color, as the earlier indication to predict the composition of the chemistry and mineral from the rock.
2. Texture, grain size, and fabric, which related with the history of the rock forming, velocity and process of crystal growth.
3. Mineralogy as the indication of rock, normally in igneous rock there are 2-4 major mineral.
4. Inclusion object, as additional information that can help on rock identification. The inclusion sometimes come inside igneous rock, and have to descript differently. This inclusion necessary when we want to know the history of the forming and the provenance of the igneous rock body.

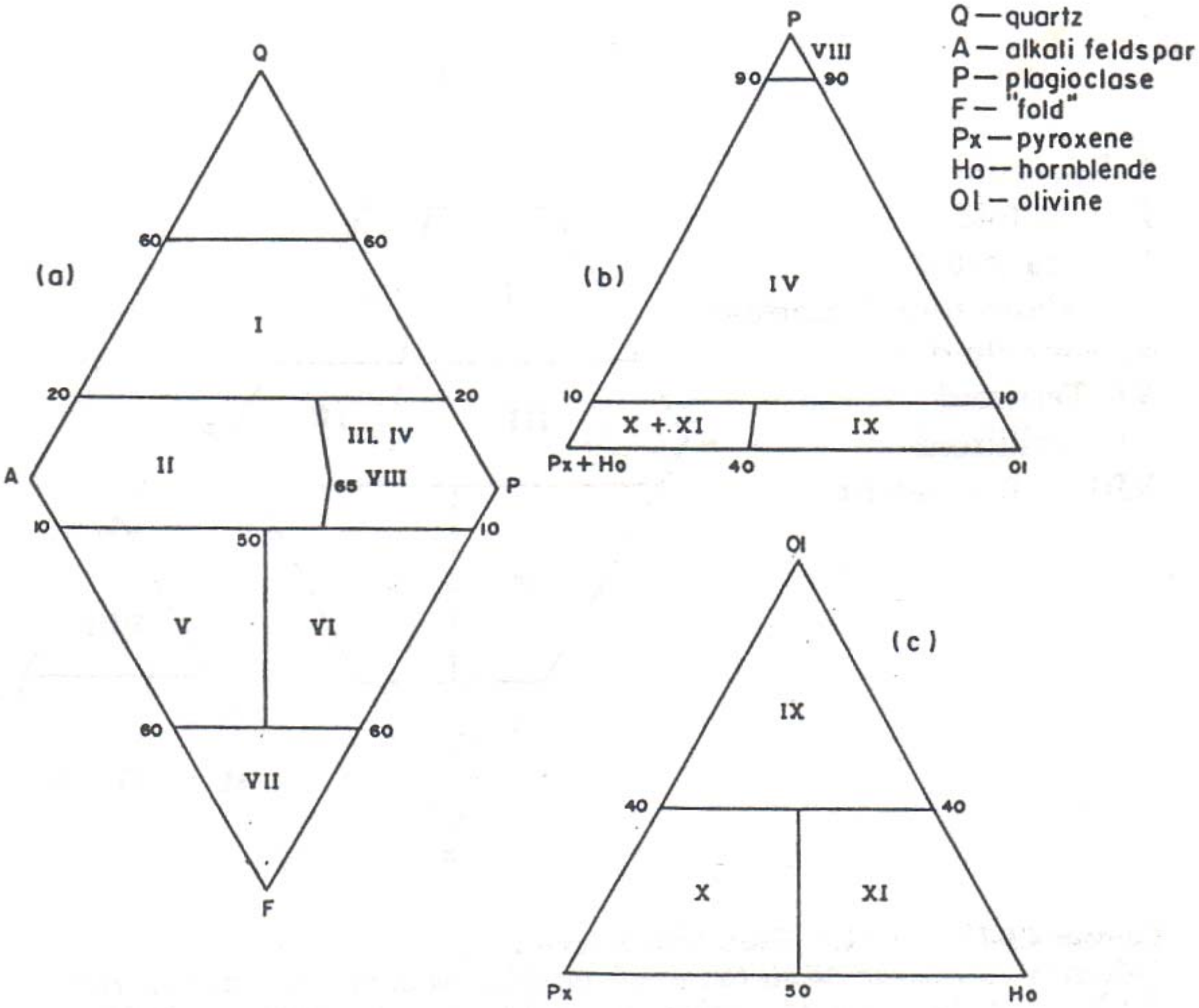


Figure 2. Classification of phaneritic igneous rock (IUGS, 1973) a) general classification, b) ultramafic, gabbroid and anorthosite classification, c) ultramafic, I.granitoid; II. Syenitoid; III. Dioritoid; IV. Gabroid; V. Foid Syenitoid; VI. Foid Dioritoid and Gabroid; VII. Foidolit; VIII Anorthosite; IX Peridotite; X. Piroxenite; XI. Hornblendite; II-IV. The qualifier Foid-Bearing is being use if there is a presence of feldspatoid mineral. IX-XI. For ultamafic rock only.

I. RYOLITOID
II. DACITOID
III. TRACHITOID
IV. ANDESITOID, BASALTOID
V. FONOLITOID
VI. TEFRITOID
VII. ULTRAMAFITIT

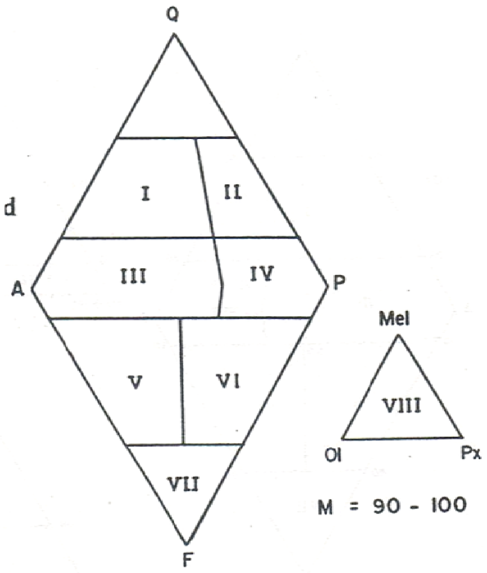


Figure 3. Classification of Aphanitic Igneous Rock.

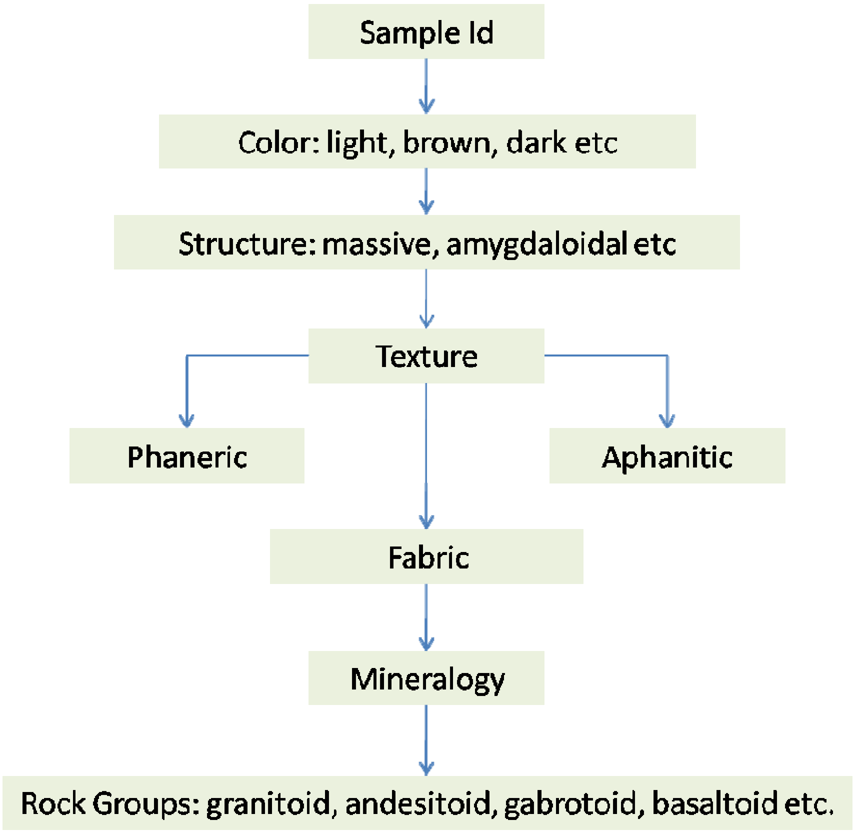

Sample Id
Color: light, brown, dark etc
Structure: massive, amygdaloidal etc
Texture
Phaneric
Aphanitic
Fabric
Mineralogy
Rock Groups: granitoid, andesitoid, gabrotoid, basaltoid etc.

Figure 4. Igneous Rock Description Flow Chart

III. Sedimentary Rock

Sedimentary rock: Rock, which is form by sedimentation, cycles (weathering-transportation-sedimentation-digenesis). The media of transportation L water, wind, glaciers, etc. form on the surface of the earth, under particular pressure and lower temperature.

Sediment composition:

- Mineral fragment or terrigenous (detrital or clastic)
- Material from chemistry process (authigenic material): carbonate, phosphate, etc.
- Allochem material (result from the previous precipitation) :fossil, organic material.

Minerals in sedimentary rock:

- Authigenic mineral:
  - Forming on sedimentation area and directly being deposit
  - Example: gypsum, calcite, anhydrite, iron oxide, halite, glaukonit
- Allogenic mineral:
  - Forming outside the sedimentation area
  - Being transport and the deposit on the sedimentation area.
  - Have to resistance from weathering and erosion during the transportation until deposition.

Texture and mineralogy of sedimentary rock usually is a reflection of the sedimentation environment. Several factors influence the forming of sedimentary rock:

1. Rock lithology (igneous rock, sedimentary rock, metamorphic rock or pyroclastic rock).
2. Stability of existing minerals.
3. Rate of erosion, how much sediment mineral that can be transport also influence how much the material that can be deposit.

Transportation on sedimentary rock resulted sorting and roundness.

Based on texture sedimentary rock can be divided into two:

1. Clastic sedimentary rock
2. Crystalline sedimentary rock

Crystalline sedimentary rock:

1. Generally consist of authigenic mineral
2. In certain Pressure and temperature, most of the time showing diagenesis effects, which cause the porosity of the rock become low or become zero.
3. Low Primary porosity and showing mosaic texture (ex: limestone)
4. Sometime there is amorph grain (such as calsedon and opal) as cement.

Table 4: Classification of Crystalline sedimentary rock based on grain size

Grain Size (mm)	Name
1 - 2	Very coarsely crystalline
0,5 – 1	Coarsely crystalline
0,25 – 0,5	Medium crystalline
0,125 – 0,25	Finely crystalline
0,063 – 0,125	Very finely crystalline
0,004 – 0,063	Microcrystalline
< 0,004	Cryptocrystalline

Clastic Sedimentary rock

- Consists of detrital (reworked; fraction), showing clastic texture (clay to boulder).
- Showing several sediment structure
- Process: weathering, erosion, transportation, and sedimentation
- Can study about the provenance material, facies, sedimentation environment, and diagenesis.

Grain Size: the major element of the clastic texture, which is related with the energy regime of transportation and sedimentation.

Table 5: Wentworth scale for grain size

Grain Size (mm)	Granule Name
> 256	Boulder
64 – 256	Couble
4 – 64	Pebble
2 – 4	Granule
1 – 2	Very coarse sand
1/2 - 1	Coarse sand
1/4 – 1/2	Medium sand
1/8 – 1/4	Fine sand
1/16 – 1/8	Very fine sand
1/256 – 1/16	Silt
< 1/256	Clay

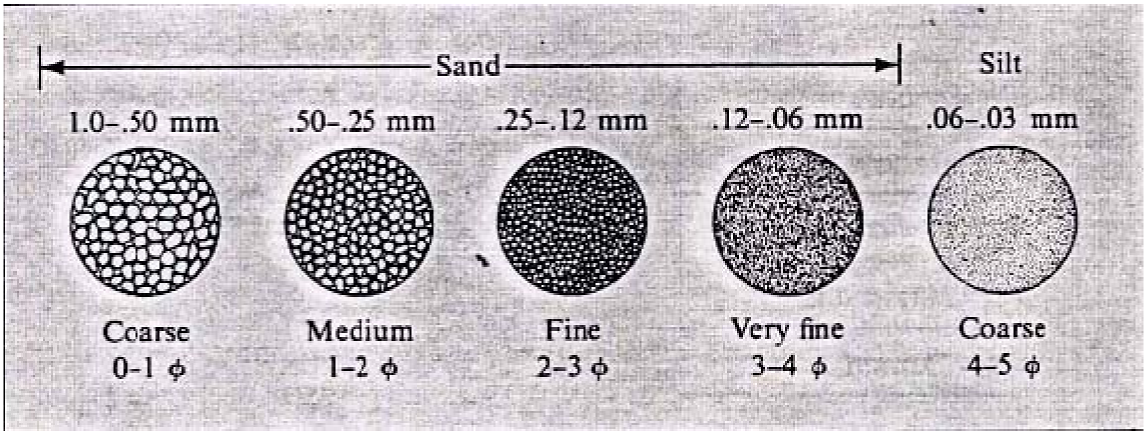


Figure 5. Grain size comperator

The grain size depends on:

1. Type of weathering : chemistry ➔ fine grain

   Mechanics ➔ coarse grain
2. Type of transportation.
3. Transportation time and distance.

Elements of clastic sedimentary rock texture:

1. Grain size: clastic granule that being transport known as fragment.
2. Groundmass (matrix): finer than granule or fragment, deposit together with the fragment.
3. Cement: has fine size, tie up the granule/fragment and matrix, being deposit after fragment and matrix.

Sorting: degree of uniformity or similarity of grain size.

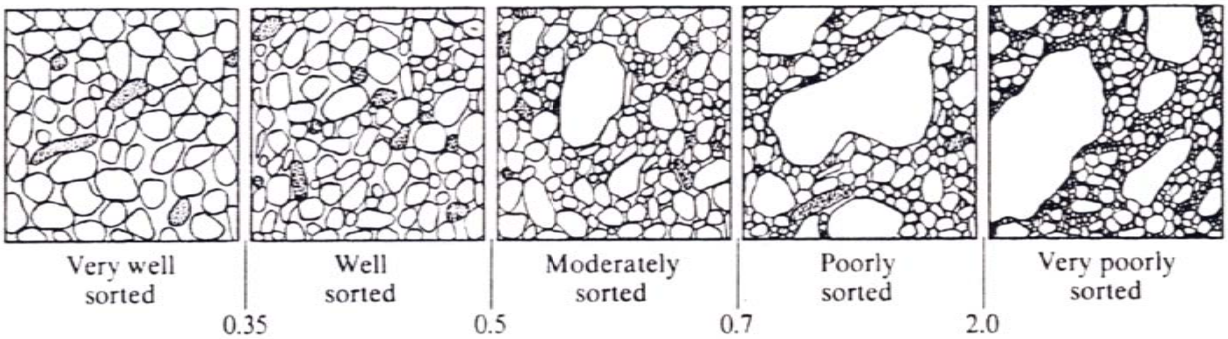


Figure 6. Sorting and degree of grain uniformity naming

Roundness: about roundness or angularity of granule, this is showing degree of abrasion during transportation process.

- Is the nature of granule surface
- Caused by transportation

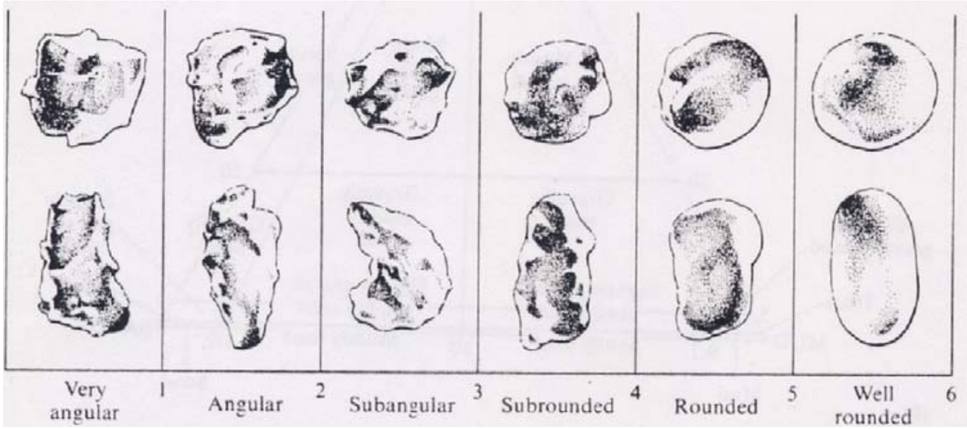


Figure 7. Degree of Roundness

Fabric: nature of granule connection as a function of grain orientation and packing. Generally can give illustration of flow direction in sedimentation also the condition of porosity and permeability of the rock. There are two type of fabric.

1. Open fabric: there is no joggle contact between one granule to the other.
2. Close fabric: there is a joggle contact between one granule to the other.

III.1 Sedimentary Rock Structure

Sedimentary rock divided into two: bedding and lamination. Bedding is used when there is a sediment layer with thickness more than 1 cm and lamination is used for layer that less than 1 cm. Type of bedding:

- Massive bedding
- Parallel lamination
- Cross lamination/ cross beds
- Convolute lamination
- Gradded bedding
- Injection structures (sandstone dykes)

Structure on bedding plane can be divided into two:

- On the bottom : load cast, flute cast
- On the top : ripple marks, mud cracks, organic marks (tracks & trails, burrow).

III.2 Elements that needed to know during sedimentary description

- Rock mix :
  - Carbonate : if the mix material is carbonate
  - Carbon : if the mix material is carbon
- Rock forming fragment: quartz, feldspar (k-Feldspar and plagioclase), rock fragment (igneous rock, sedimentary rock, metamorphic rock and pyroclastic rock).
- Cement and matrix:
  - Carbonate cement, silicate, Ferro oxide, anhydrite, glaukonite.
  - Matix sand, silt, and clay.
- Color/luster: rock color description should representative (example: gray with black line, black shine, etc).

- Supporting mineral: glaukonite, pyrite, hematite, pyroxene, olivine, biotite, muscovite, carbon, etc.
- Fossil content (if there is fossil content, mention the type of the fossil ex: foraminifera, etc)
- Existing sediment structure: bedding, graded bedding, parallel lamination, etc.
- Porosity:
    - Good ➔ can absorb water
    - Poor ➔ can not absorb water
    - Medium ➔ in between good and poor porosity
- Compactness: easy to squeezed, brittle, compact, soft, solid, hard, etc (description should representatively).

III.3 Siliciclastic Sedimentary Rock

Rocks that have grain size from medium-coarse: sandstone, conglomerate, and breccias and fine grain size: mudrock.

III.3.1 Sandstone

Sandstone classification:

1. Siliciclastic sandstone (terrigenous grain)
    a. Epiclastic sandstone: deposit from rework of the existing rock because of weathering and erosion, included volcanic and non-volcanic rock.
    b. Volcaniclastic sandstone: consist of volcanic material (from rework or not), included pyroclastic and epiclastic rock.
2. Non-silliciclastic sandstone (carbonate granule and evaporate).

Sandstone:

- Texture: the grain size (sand 0.125-2 mm), grain shape (angular, roundness, etc), sorting, fabric (included the orientation, grain packing, grain contact, relation between grain and matrix), maturity texture, porosity, permeability, and sediment structure.
- Maturity texture:
    - Immature sediment texture: dominant matrix, poor sorting, angular granule.

  - Mature sediment texture: less matrix, sorting medium-well, granule semi-round to round.
- Composition: granule (lithic fragment, quartz, feldspar, and other minerals), matrix and cement.
- Sandstone classification
  - Parameter:
    - grain (stable or not stable): quartz, feldspar, lithic fragment
    - clay matrix (from rework or rock alteration)
    - the presence of clay mineral: arenite (matrix < 15%) and wacke (matrix > 15%).
  - General classification (Gilbert, 1982) and (Folk, 1974); quartz sandstone, arkose sandstone, lithic sandstone, and greywacke sandstone.

Quartz Sandstone (Quartz Arenites): association with aeolian sediment, beach, shelf (stable crust environment), maturity degree: mature to super-mature, interbedded with shallow marine limestones, generally sediment bed structure is cross bedding, mineralogy quartz, quartzite chert with 90% silicate cement, carbonate and hematite.

Arkoses sandstone: feldspar grain has higher percentage, red or pink color, deposit environment non marine, and most of them on fluviatile system, maturity degree: immature to submature, mineralogy: quartz < 90% (average 50-60 %), feldspar > lithic fragment 10-75% (average 20-40%), carbonate cement, feldspar silicate, hematite, sulfate mineral (barite, pyrite, and clay mineral).

Litharenite: the naming for this type depends on the presence of what type of lithic or fragments, normally found on deltaic or fluvial environment. The lithic fragment mineralogy 10-80%, feldspar, quartz, carbonate cement, silica, clay mineral, iron oxide, pyrite, clay or chlorite matrix (if exist).

Greywackes: most of the rocks hard, massive and have dark grey color with abundance matrix, feldspar and normally the lithic not exist, being deposit under turbidities current on deep basin, showing turbidity sediment structure.

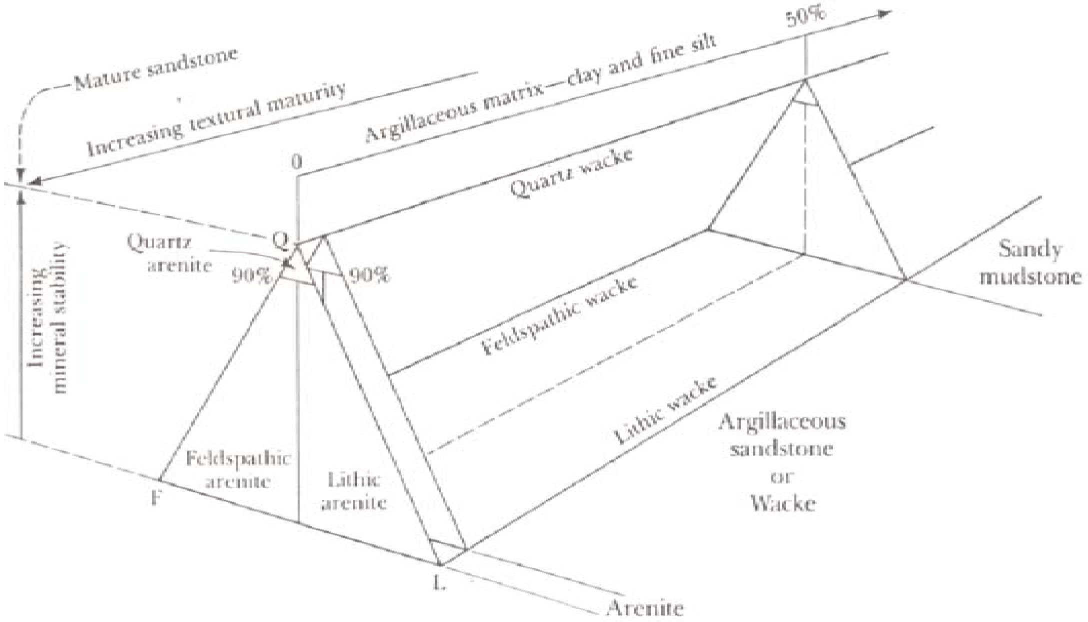


Figure 8. Sandstone classification (Gilbert, 1982)

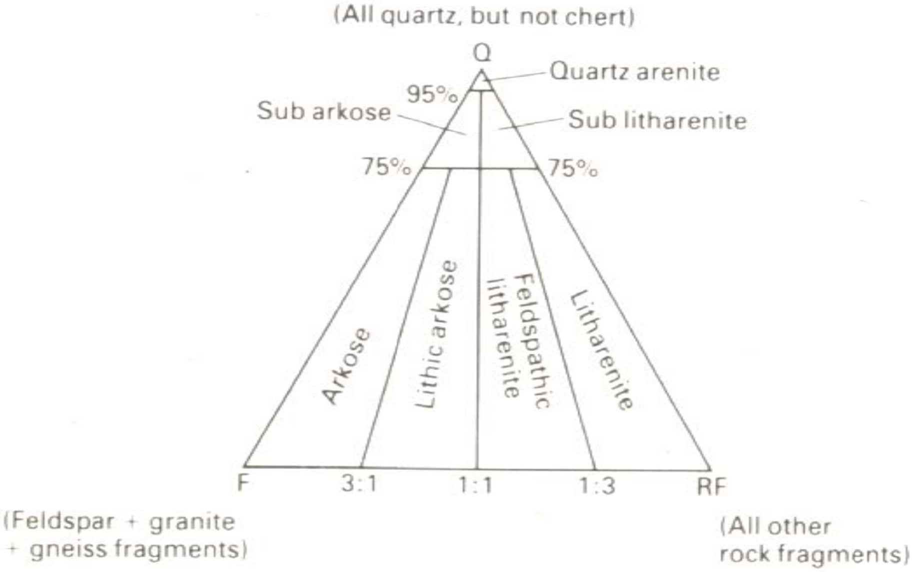


Figure 9. Sandstone Classification (Folk, 1974)

Conglomerate and Breccia

The important appearance when descript this type of rock is the type of clastic element that presence and the texture of the rock. Based on the origin of the clastic element that compose the conglomerate and breccias can be divided into two:

1. Intar formation clastic, which come from inside the depositional basin, a lot of mudrock fragments or micritic limestone which release because of the erosion or preservation along the beach line.
2. Extra formation clastic, which come from outside the depositional basin, and older than the sediment on the related basin.

Type of conglomerate base on the type of clastic:

1. Polymictic conglomerate: consist of different types of clastic.
2. Monomictic/oligomictic conglomerate: consist of one type of clastic.

For interpretation the depositional mechanism of conglomerate have to descript the texture (is the texture clast supported conglomerates or matrix supported conglomerates), shape, size, and rock fragment orientation, thickness, and bedding geometry, and sediment structure.

Conglomerate and breccias most of the time being deposited on glacial environment, alluvial fan, and braided stream. The re-sediment conglomerate on the deep water environment normally associate with the turbidit.

MudRock

Mudrock is the general term that used for sedimentary rock that compose by clay-silt particles, and other mineral that might be existing. Mudrock deposit on the river floodplain environment, lake, low energy shoreline, delta, outer marine shelf and deep ocean basin.

Carbonate Rock (Limestone and Dolomite)

Carbonate rock: all rock that consists of carbonate salt, and on practically known as limestone and dolomite.

Carbonate rock-forming component:

1. Carbonate granules (allochems):
    a. Skeletral granules: fragment from the hardest part of calcareous organism and shell that never break like mollusca, echinoid, ostracoda and foraminifera.
    b. Ooid: has speroidal shape, sand size with cortex (outer skin) aragonite or calcite which form by the chemistry accretion around the core particle.
    c. Pellets: has speroidal or ellipsoid shape, sand size, consist of micrit, do not have inside structure.
    d. Lithoclast: carbonate rock fragment
        - Intar clast: the carbonate rock fragment which form earlier (come from the same basin).
        - Extra clast: the carbonate rock fragment which come from different age or different basin.
2. Clay carbonate micrit: aggregate of calcite with microgranular shape.
3. Spar cement: granular calcite which being re-crystallize on the empty room on the carbonate deposit or limestone deposit, especially the empty room between granule and on the fossil cavity.

Chemistry/mineral composition:

- Aragonite $CaCO_3$ (orthorhombic): from the direct precipitation of seawater, has unstable fiber form.
- Calcite $CaCO_3$ (hexagonal): the mineral more form, has a good/spar crystal. When react with the red alizarin will become red color.
- Dolomite $CaMg(CO_3)_2$: has rhombus form, nor react with the red alizarin, most of delimitation come from calcite.
- High magnesium calcite: solid liquid of $MgCO_3$ inside the calcite.

- Magnesite $MgCO_3$: normally associate with evaporation.
- Siderite $FeCO_3$

Rock carbonate texture:

1. Primary texture concerning organic framework texture, clastic texture, and matrix texture.
2. Secondary texture/diagenesis texture concerning on crystalinity which showing by cement that fill the cavities between the granules, re-crystallization partial or all the matrix or framework or granules.

Classification of carbonate rock:

1. Grabau classification:
   - Based on granule size: calsirudite (> 2mm), calcarenite (62 λm – 2 mm), calsilutite (62 λm)
2. Folk classification:
   - Based on composition: allochem, matrix, and cement. Bio (skeletral grain), oo (ooid), pel (peloid), intar (intarclast).
3. Dunham Classification:
   - Based on texture ➔ percentage of grain versus matrix
   - Mudstone: carbonate mud >>> grain (mud supported), grain < 10%
   - Wackestone: carbonate mud >grain (grain-mud supported), grain > 10%
   - Packestone: grain>carbonate mud (mud-grain supported)
   - Grainstone: grain>>>carbonate mud (grain supported)
   - Boundstone: consist of a framework
   - Crystalline carbonate: consist of crystal, and the depositional texture unknown.
4. Embry and Klovan classification:
   - Based on the existing of carbonate mud between framework or framework fractures.

  - Framestone: all consist of organic framework such as coral, bryozoa, algae, matrix < 10%
  - Bindstone: consist of framework/fracture of organic framework such as coral, which was re-bind by the limestone encrusting of the red algae.
  - Bafflestone: consist of organic framework such as coral in growth position and covered by limestone mud.
  - Rudstone: re-work of a reef and accumulating locally or being transport by gravity force, without any limestone mud between its fragments.
  - Floatstone: consist of organic framework cutting which float on the limestone mud.

Porosity is the comparison between the cavities to total rock volume in percentage. There are two type of porosity:

- Primary porosity: form during depositional-early diagenesis, example intercrystalline, intrarcrystalline, intergranular, intragranular
- Secondary porosity: from during advanced diagenesis (mesogenesis-telogenesis) example: porosity because of fracturing, shrinkage and dissolution (grain, cement, matrix).

IV Metamorphic Rock

Metamorphic rock: rock that form because of the changes of pressure (P), temperature (T) or both, which enter the new equilibrium without any changes on the chemistry composition (isocheims) and without go through liquid phase (in solid phase) with temperature around 200-800^{0}C.

The changes that occurred on metamorphism:

1. Texture and structure, which is the reflection of the forming history.
2. Mineral association

Type of metamorphism:

1. Thermal metamorphism: occurred when the temperature increase and normally found around the body intrusion or plutonic rock, the area of contact can be meters until kilometer, which depend on the intrusion rock composition and the intruded rock, dimension and depth of the intrusion.
2. Regional metamorphism (dynamo thermal): occurred when the temperature and pressure increase together, normally found on orogenesis path which cover a big area, progressively change from low P&T to high P&T.
3. Cataclastic metamorphism (kinematic/dislocation): occurred because of movement of the fault which caused the fracturing zone, granulation, fault breccias (shallow), milonite, filonite (deeper) and followed by re-crystallization.
4. Burial metamorphism: occurred because of loading, normally on sedimentation basin, the changes of mineralogy indicated by the presence of zeolite mineral.
5. Sea floor metamorphism: occurred because of the spreading of ocean floor, in the mid ridge ocean, when the lithosphere plate form.

Metamorphic rock structure:

- Foliation structure (schistosity): parallel structure because of the flat/prismatic mineral, often occurred on the regional and cataclastic metamorphism.
- Non-foliation structure: form by equidimensional minerals, which normally found on thermal metamorphism.

Foliation structure:

Slaty:

- Planar foliation structure, which found on the cleavage of slate rock.
- Mica mineral start to presence.

Phylitic:

- The re-crystallization coarser than slaty
- The rock more shiny than slate rock (more mica mineral)
- Start differentiating flat and granular mineral although not so clear/perfect.

Schistose:

- Repetition structure of flat and granular mineral
- The flat mineral has continuous orientation
- Known as close schistosity

Gneissic:

- Repetition structure of flat and granular mineral
- The flat mineral orientation not continue
- Known as open schistosity

Milonitic:

- Showing the scratch cause of strong milling.

Filonitic:

- The characteristic and the appearance same with the milonitic (filonitic has fine grain)
- The re-crystallization done
- Showing silky luster

Non-foliation structure:

1. Granulose (granoblastic) : consist of granular mineral
2. Hornfelsic: identically with granoblastic but the mineral are equidimensional, no orientation, specially because of thermal metamorphism.

Crystalloblastic texture of metamorphic rock:

- Lepidoblastic : consists of flat or tabular minerals, such as mica mineral (muscovite, biotite).
- Nematoblastic: consist of prismatic minerals, such as plagioclase mineral, k-feldspar, pyroxene.
- Granoblastic: consist of granular minerals (equidimensional), with suture boundary not regular, with anhedral mineral, such as quartz.
- Homeoblastic: consist of one texture only, such as lepidoblastic only.
- Heteroblastic: consist of more than one texture, such as lepidoblastic combine with granoblastic.

Another special texture:

- Relic texture: the relic texture which form before the metamorphism (which show the origin of the rock before metamorphism). The naming will using blasto in front and then follow by the relic texture example: blastoporphyritic (the origin rock has porphyritic texture), blasto-ophitic (the origin rock has ophitic texture).
- Crystalloblastic texture: every texture that form when the metamorphism occurred. The naming of this texture will follow by blastic in the end of the name, which is used to give name of the texture that form by metamorphism re-crystallization process, example porphyroblastic (metamorphic rock which showing the similarity porphyritic texture on igneous rock, but this texture is form by the metamorphism re-crystallization.
- The meta word in the beginning name of metamorphic rock if the characteristic from the origin rock still can be recognized, example metasediment, metaclastic, metagraywacke, metavolcanic, etc.

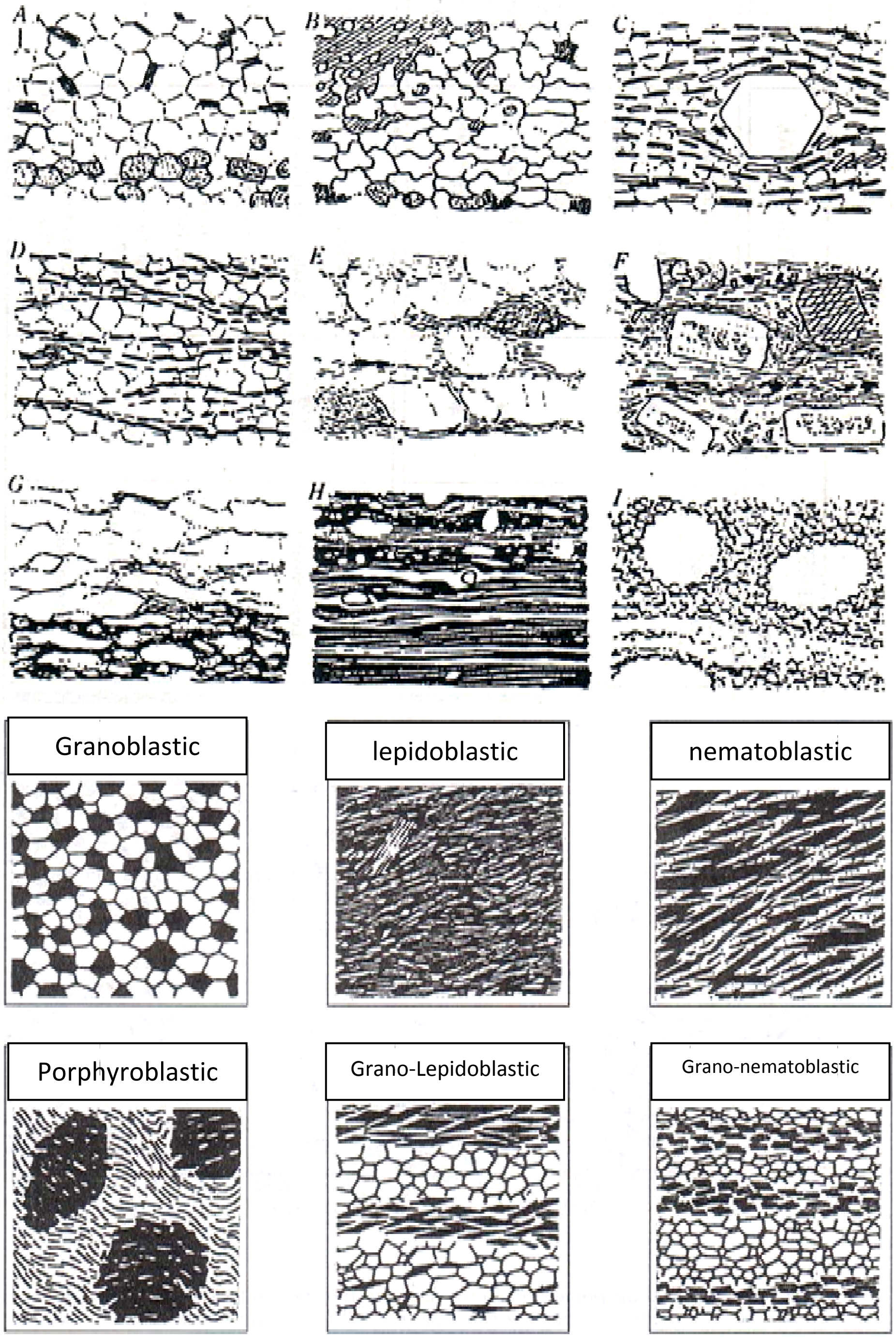


Figure 10. Metamorphic texture, A. Granoblastic, B. Granoblastic with un-regular granules, C. Schistose with porphyroblast, D. Schistose with granoblastic lenticuler, E.Filitic, F.Gneissose, G.Milonitic, H.Milonitic, I.Granoblastic in Milonite.

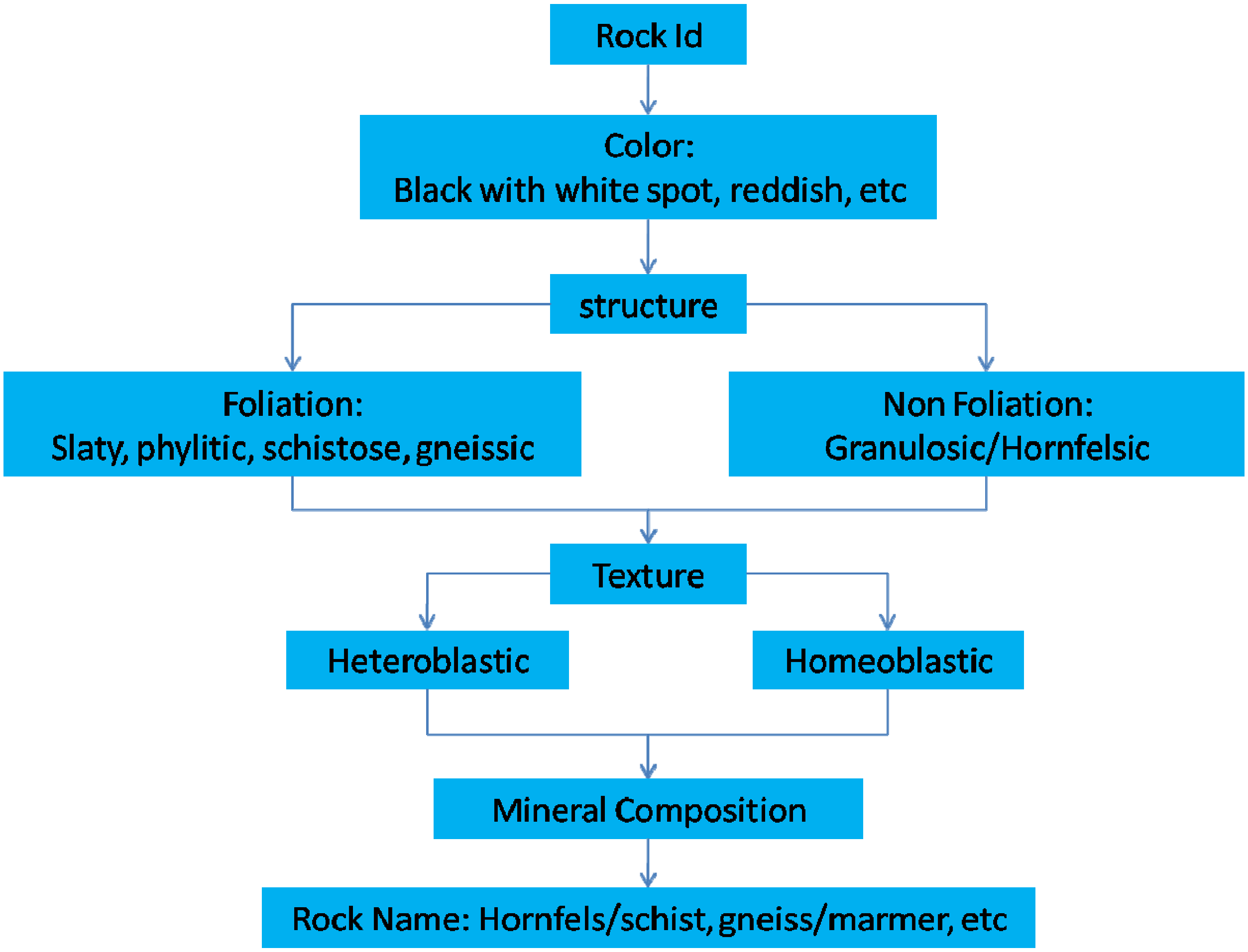


Figure 11. Metamorphic Rock Flowchart Description

v. Porosity Calculation

From the viewpoint of petroleum engineers, the two most important properties of a reservoir rock are porosity and permeability. Porosity is a measure of storage capacity of a reservoir. It is defined as the ratio of the pore volume to bulk volume, and is may be expressed as either a percent or a fraction. In equation form

$$\phi = \frac{pore\ volume}{bulk\ volume} = \frac{bulk\ volume - grain\ volume}{bulk\ volume}$$

Two types of porosity may be measured: total or absolute porosity and effective porosity. Total porosity is the ratio of all the pore spaces in a rock to the bulk volume of the rock. Effective porosity e is the ratio of interconnected void spaces to the bulk volume. Thus, only the effective porosity contains fluids that can be produced from wells. For granular materials such as sandstone, the effective porosity may approach the total porosity, however, for shales and for highly cemented or vugular rocks such as some limestones, large variations may exist between effective and total porosity.

Porosity may be classified according to its origin as either primary or secondary. Primary or original porosity is developed during deposition of the sediment. Secondary porosity is caused by some geologic process subsequent to formation of the deposit. These changes in the original pore spaces may be created by ground stresses, water movement, or various types of geological activities after the original sediments were deposited. Fracturing or formation of solution cavities often will increase the original porosity of the rock.

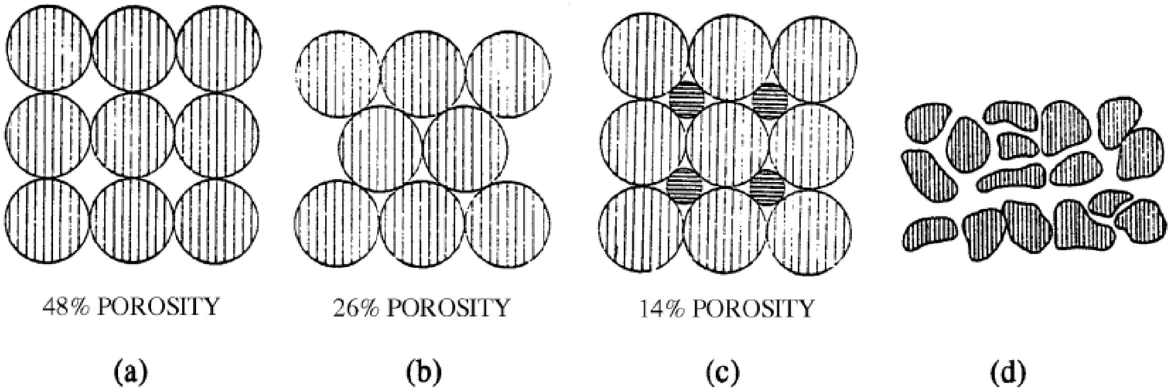


Figure 12. Cubic packing (a), rhombohedral (b), cubic packing with two grain sizes (c), and typical sand with irregular grain shape (d)

For a uniform rock grain size, porosity is independent of the size of the grains. A maximum theoretical porosity of 48% is achieved with cubic packing of spherical grains, as shown in Fig. 12a. Rhombohedral packing, which is more representative of reservoir conditions, is shown in Fig. 12b; the porosity for this packing is 26%. If a second, 21 smaller size of spherical grains is introduced into cubic packing (Fig. 12c), the porosity decreases from 48% to 14%. Thus, porosity is dependent on the grain size distribution and the arrangement of the grains, as well as the amount of cementing materials. Not all grains are spherical, and grain shape influences porosity. Typical reservoir sand is illustrated in Fig. 12d.

V.1 Effect of Compaction on Porosity

Compaction is the process of volume reduction due to an externally applied pressure. For extreme compaction pressures, all materials show some irreversible change in porosity. This is due to distortion and crushing of the grain or matrix elements of the materials, and in some cases, recrystallization. The variation of porosity with change in pressure can be represented by

$$\phi_2 = \phi_1 e^{C_f (P_2 - P_1)}$$

where Φ2 and Φ1 are porosities at pressure P2 and P1 respectively, and cf is formation compressibility. Formation compressibility is defined as summation of both grain and pore compressibility. For most petroleum reservoirs, grain compressibility is considered to be negligible. Formation compressibility can be expressed as

$$c_f = \frac{1}{V}\frac{dV}{dP}$$

where dP is change in reservoir pressure. For porous rocks, the compressibility depends explicitly on porosity.

V.2 Porosity Determination by Liquid Saturating Method

The determination of the effective liquid porosity of a porous plug is the initial part of the measurement of capillary pressure using porous plate method in core laboratories. Before27 the capillary pressure is determined the volume of the saturating liquid (brine or oil) in the core (rock sample) must be known. Thus, the effective liquid porosity of the core can be calculated in the beginning of capillary pressure measurement.

Procedure:

1. Weigh dry Berea plug Wdry, measure its diameter D, and length L, with caliper (1 core for each group).
2. Put the cores in the beaker inside a vacuum container, run vacuum pump about 1 hour.
3. Saturate the cores with 36 g/l NaCl brine, brine = 1.02g/cm3.
4. Weigh the saturated cores, Wsat.

Calculations and report:

1. Calculate the saturated brine weight, Wbrine = Wsat-Wdry.
2. Calculate the pore volume (saturated brine volume), Vp = Wsat/ρbrine.
3. Calculate effective porosity, Φe = Vp/Vb.

Core No.: D: cm, L: cm.

W_{dry} (g)	W_{sat} (g)	W_{brine} (g)	V_p (cm^3)	ϕ_e

VI Major Element Analysis of Rocks and Sediments by Atomic Absorption Spectroscopy

The chemical analysis of rocks and sediments is performed for variety environmental and petrological purposes. For examples, chemical data is used in the identification of various rock types; also, sediments contain significantly higher concentrations of many metals than are found in the overlying water; as such, they must be analyzed for potential pollutant contributions to the environment.

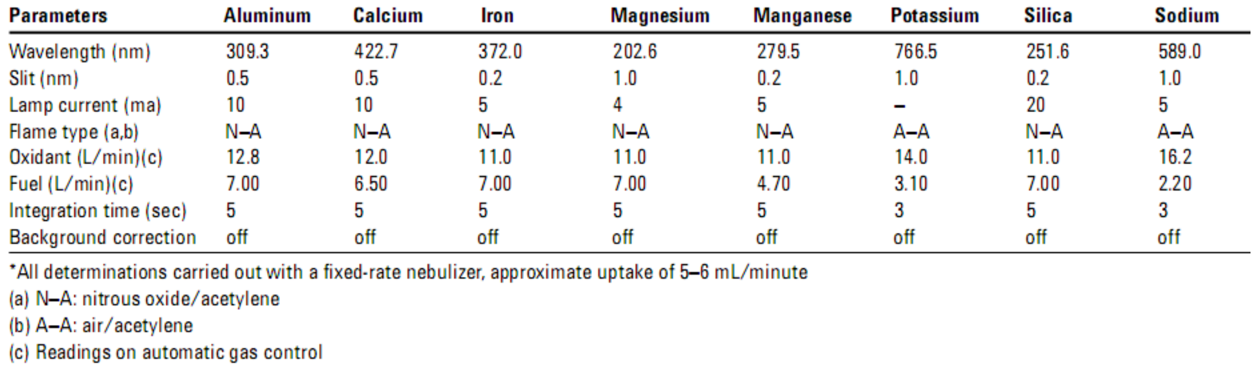
Rock and/or sediment samples are dried, ground and homogenized. An aliquot is fused with a mixture of lithium metaborate and lithium tetraborate, in a muffle furnace at 1000^{o}C. The resulting bead is dissolved in acidified, boiling, deionized water, and the solutions are analyzed by flame atomic absorption spectroscopy after the addition of appropriate modifiers.

Procedure:

1. Clean all glassware by rinsing, first with dilute nitric acid (1+1), and then with demineralized water.
2. Dry the sediment sample by an appropriate procedure such as freeze drying, or in oven at 105^{o}C. If the sediment > 100g, split it down to less than 100 g by use of a non metallic sample splitter or by coning and quartering.
3. Grind the sediment or rock sample with mixer mill or an agate mortar and pestle until all material is finer than 100 mesh.
4. Transfer approximately 1.2 g of flux mixture to a waxed or plastic coated weighing paper.
5. Weigh and transfer 0.2 g of ground sample to the flux mixture and mix by rolling successive corners of the paper about 30 times.
6. Transfer the combined sample/flux to a graphite crucible, and tamp down.
7. Weigh appropriate standard materials and treat as unknowns. Carry several blanks through the procedure by using only flux and treat as unknowns.

8. Fuse mixtures in a muffle furnace, pre-heated to 1000ºC for 30 minutes.
9. Remove the crucibles from the furnace and allow to cool, dislodge the beads by gentle tapping or with a spatula.
10. Place the bead in an acid washed 250 ml plastic bottle and add a ¾ to 1 inch stirring bar.
11. Add approximately 50 ml boiling demineralized water, place the bottle on a magnetic stirrer and mix.
12. Add 5 ml dilute nitric acid (1+1) to each bottle and stir rapidly for about 60 minutes. Cap the bottle lightly, during the stirring, to prevent both contamination and possible spattering.
13. After 60 minutes, remove the bottles from the stirres and add about 100 ml demineralized water to prevent the polymerization of silica.
14. Pour each solution into 200 ml volumetric flask, using a funnel in order to retain the stirring bar. Rinse the bottle, cap, and bring to mark with demineralized water. Pour the solution back into the plastic bottle for storage. Add 10 ml CsCl and 20 ml H_3BO_3 solution into each bottle.
15. Prepare the mixed salt working standards and to each 100 mL, add 5 mL CsCl solution, and 10 mL H_3BO_3 solution.
16. Set up the atomic absorption spectrophotometer and analyze the solutions for Fe, Mn, Mg, Si, and Al. Dilute samples if required, using the standard diluent solution and add appropriate quantities of CsCl and H_3BO_3 solutions.
17. Transfer 10.0 mL aliquots of each sample and working standard solution to 100 mL volumetric flasks and dilute to 100 mL. Transfer solutions to plastic bottles and add 5 mL CsCl and 10 mL H_3BO_3 solutions to each.
18. Set up the atomic absorption spectrophotometer and analyze the solutions for Ca, K, and Na. Dilute samples if required, using the standard diluent solution and add appropriate amounts of CsCl and H_3BO_3 solutions.

Table 6: Atomic absorption spectrophotometer criteria



Parameters	Aluminum	Calcium	Iron	Magnesium	Manganese	Potassium	Silica	Sodium
Wavelength (nm)	309.3	422.7	372.0	202.6	279.5	766.5	251.6	589.0
Slit (nm)	0.5	0.5	0.2	1.0	0.2	1.0	0.2	1.0
Lamp current (ma)	10	10	5	4	5	–	20	5
Flame type (a,b)	N–A	N–A	N–A	N–A	N–A	A–A	N–A	A–A
Oxidant (L/min)(c)	12.8	12.0	11.0	11.0	11.0	14.0	11.0	16.2
Fuel (L/min)(c)	7.00	6.50	7.00	7.00	4.70	3.10	7.00	2.20
Integration time (sec)	5	5	5	5	5	3	5	3
Background correction	off	off	off	off	off	off	off	off

*All determinations carried out with a fixed-rate nebulizer, approximate uptake of 5–6 mL/minute

(a) N–A: nitrous oxide/acetylene

(b) A–A: air/acetylene

(c) Readings on automatic gas control

Calculations and Reporting

- Determine the concentration of each constituent (Fe, Mn, Mg, Si, and Al) in each sample solution while aspirating each sample and record, the results (average of 3 readings once the system has stabilized).
- The actual concentration of each constituent in the sample can be obtained by multiplying the concentration in each sample solution by 1000, if no dilutions are made.
- Determine the concentration of each constituent (Ca, K, and Na) in each sample solution while aspirating each sample and record, the results (average of 3 readings once the system has stabilized). The actual concentration of each constituent in the sample can be obtained by multiplying the concentration in each sample solution by 10,000, if no dilutions are made.
- The reporting for each constituent are as follows: aluminium (nearest 1000 mg/kg), calcium (nearest 1000 mg/kg), iron (nearest 1000 mg/kg), magnesium (nearest 1000 mg/kg), manganese (nearest 100 mg/kg), potassium (nearest 1000 mg/kg), silica (nearest 1000 mg/kg), and sodium (nearest 1000 mg/kg). As 10,000 mg/kg equals 1%, all but Mn should be reported to the nearest tenth of a percent; Mn should be reported to the nearest hundredth of a percent.